"RIVER HYDROLOGY IN PERMAFROST AREAS"

Workshop Seminar on Permafrost,
CNC/IHD Calgary, Alberta
Feb. 26-28, 1974

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A B S T R A C T

An examination of permeable, relatively impermeable, and permafrost basins indicates that rainfall/runoff relationships are generally of the same order of magnitude and variability under all basin conditions. However, highest yields were observed in permafrost basins.

Data dealing with bank stability, sediment transport, the annual ice regime, and the incidence of river icings are extremely limited in permafrost regions. The operation of a small number of index basins to investigate subsurface conditions, the development of standard river behaviour surveys, and the establishment of a central agency for the compilation and exchange of hydrologic data from permafrost areas are recommended.

In addition, the question of professional responsibility for the development of northern waters is raised.

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Professor, University of Manitoba

An examination of river hydrology in permafrost regions is necessarily theoretical. In 1973, canvassing over 30 Canadian consultants, governmental agencies, study centers, and universities for field data dealing with sub-arctic or arctic rainfall-runoff relationships, sediment transport phenomena, and river basin morphology produced a paltry amount of information. Most researchers were either new to northern regions or had not the elaborate facilities required to obtain reliable data.

However, a few encouraging studies such as those conducted by Anderson and Mackay (1973) or Dingman (1973) do provide field data from permafrost basins with which the adjustments to conventional hydrologic modelling can be assessed.

River Basin Behaviour

The simplified hydrologic flow model shown in Figure 1 allows for the combination of direct runoff, interflow, and groundwater discharge to provide streamflow in quantities varying widely from base flow to peak flow events depending on which and how many components of the system are active at one time (Newbury, Cherry, and Cox, 1969). The components of direct runoff and interflow are important in short duration events following a snowmelt or rainstorm period while the groundwater discharge component provides the long-term base flow component of the flow.

In the opinions canvassed, a wide divergence was apparent on the functioning of the interflow and groundwater terms in permafrost regions. It was speculated on one hand that the interflow and groundwater components would be confined to the active layer only and it was suggested that, as a result, runoff ratios (runoff/rainfall ratio) would be higher. Similarly, base flows would not persist throughout the winter unless unfrozen surface storage primarily in open water bodies was available. On the other hand, a considerable body of opinion supported the permafrost basin model suggested by Williams and van Everdingen (1973) in which the permanently frozen areas of a watershed were treated as intermittent "confining beds of low but finite permeability." There are many instances of developed water supplies, springs and artesian acquifers

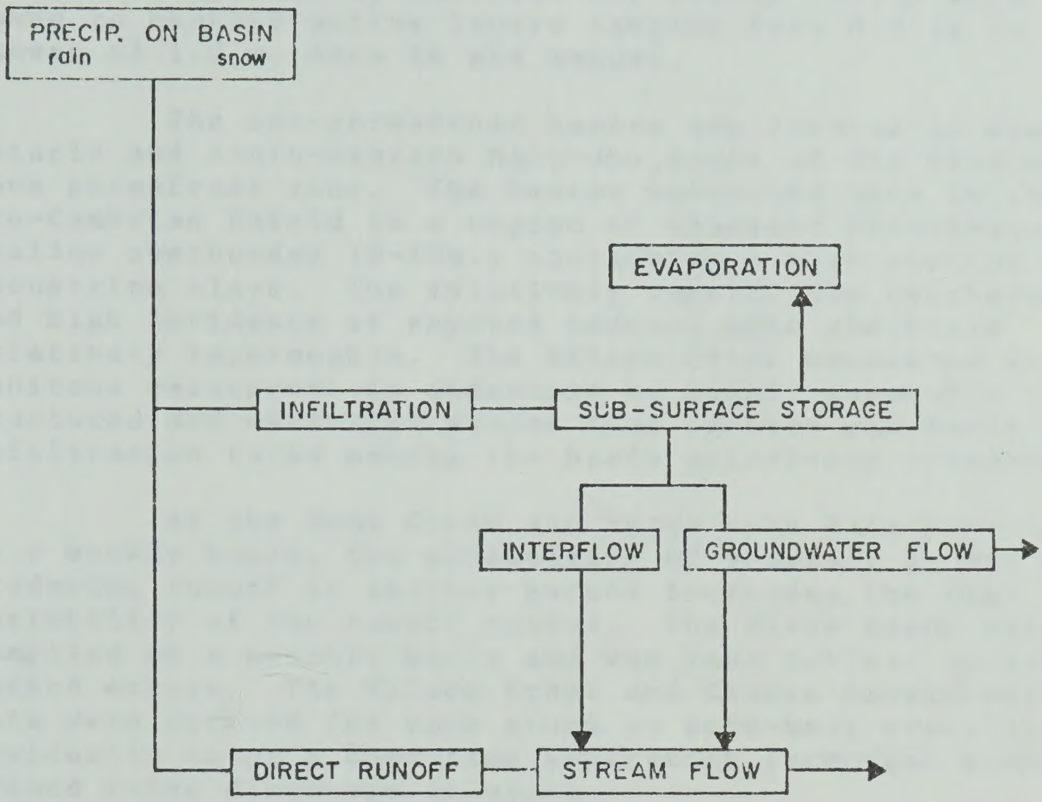


Figure 1: Schematic Diagram of the Hydrologic Process

in permafrost basins which support the latter contention (Kane, Carlson, Bowers, 1973; Kane and Slaughter, 1973; Linell, 1973; Sherman, 1973).

Whether or not the sub-surface components of a hydrologic system play a significantly different role in permafrost regions as compared to better known non-permafrost regions should be reflected in the runoff ratios where high values would indicate a low capacity for interflow and subsurface storage. The highly variable runoff ratios for 3 permafrost and 2 non-permafrost basins are listed in Table I. The Glenn Creek basin near Fairbanks, Alaska as reported by Dingman (1973) contains a permanently frozen soil zone beneath a 0.3 to 1.0 m. seasonal thaw zone

throughout two thirds of the watershed. The Boot Creek and Peter Lake basins near Inuvik and Reindeer Station N.W.T. as reported by Anderson and Mackay (1973) were found to contain active layers ranging from 0.3 to in excess of 1.0 m. deep in mid August.

The non-permafrost basins are located in western Ontario and south-western Manitoba,south of the discontinuous permafrost zone. The Kenora watershed lies in the Pre-Cambrian Shield in a region of sparsely distributed shallow overburden (0-10m.) containing a high portion of lacustrine clays. The relatively impermeable overburden and high incidence of exposed bedrock make the basin relatively impermeable. The Wilson Creek watershed on the Manitoba escarpment is underlain by highly permeable fractured and weathered shales that exhibit extremely high infiltration rates making the basin relatively permeable.

As the Boot Creek and Peter Lake data were compiled on a weekly basis, the possibility of rainfall in one period producing runoff in another period increases the high variability of the runoff ratios. The Glenn Creek data was compiled on a monthly basis and was less subject to time period errors. The Wilson Creek and Kenora watersheds data were derived for each storm or snow-melt event individually using a base flow separation technique based on ground water discharge dilution.

In Figure 2, the rainfall/runoff ratios for all basins have been plotted without attempting a further distinction of individual storm parameters. Without further data, it is apparent that, in general, the impermeable basin exhibits a slightly higher yield of runoff per unit of storm rainfall than the more permeable basin. Discounting the extreme ratios for permafrost basins as time period errors, it remains apparent that the majority of storm events produce an even higher yield of runoff than the relatively impermeable basin. However, the general magnitude of the rainfall/runoff ratios does not vary widely from southern basins and the preliminary evidence would seem to support the intermittent limited permeability model suggested by Williams and von Everdingen (1973) as being a suitable perceptual model for a permafrost basin. Data dealing with midwinter base flows in small basins would be useful as a further indicator of sub-surface conditions but none were available.

TABLE I

RAINFALL/RUNOFF RATIOS FOR PERMAFROST AND NON-PERMAFROST BASINS

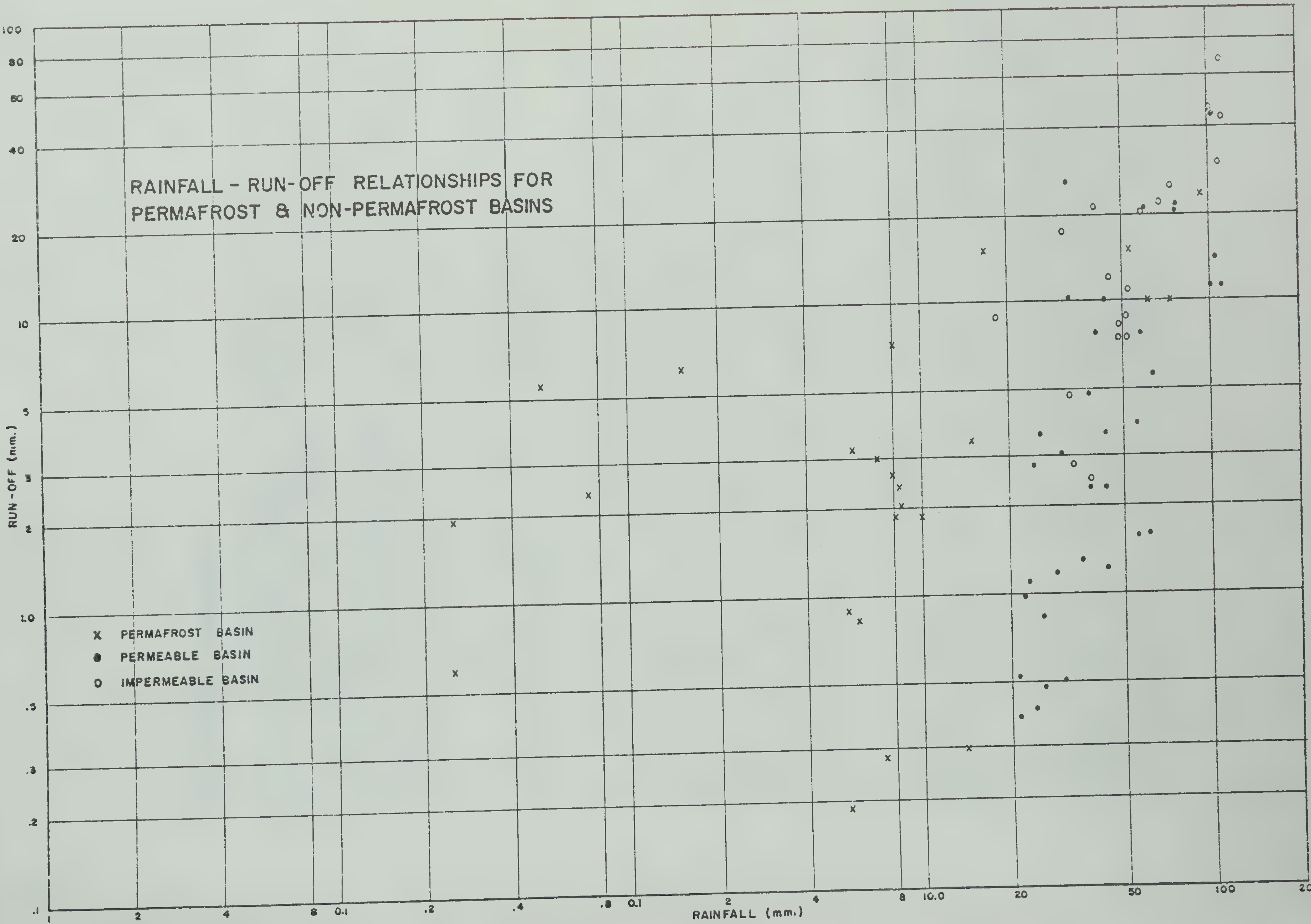
WILSON CREEK (1)			GLENN CREEK (2)			BOOT CREEK (3)			PETER LAKE (4)			KENORA WATERSHED (5)		
Permeable			Permafrost			Permafrost			Permafrost			Impermeable		
Rain	Run-off	$\frac{RO}{R}$	R	RO	$\frac{RO}{R}$	R	RO	$\frac{RO}{R}$	R	RO	$\frac{RO}{R}$	R	RO	$\frac{RO}{R}$
mm	mm		mm	mm		mm	mm		mm	mm		mm	mm	
21.1	0.38	.02	62	10	.16	7.24	0.28	.04	1.52	6.27	4.11	125.	42.2	.34
25.9	3.55	.14	74	10	.14	5.46	0.19	.04	0.51	5.61	11.04	117.	67.0	.57
24.1	0.41	.02	95	23	.24	13.97	0.30	.02	8.38	2.39	.29	18.5	8.9	.48
55.9	3.81	.07	17	15	.88	21.96	1.01	.05	8.50	2.05e	.24e	40.7	21.1	.52
25.9	0.48	.02	7	3	.43	10.03	1.89	.19	8.13	1.88e	.23e	46.8	12.2	.26
38.1	4.82	.13	54	15	.36	0.73	2.37	3.25	7.87	2.61	.33	33.	4.8	.15
30.5	0.51	.02	31	1	.03	8.13	7.23	.89				74.7	24.6	.33
63.5	5.59	.09	29	0	0	5.84	3.26	.56				33.8	2.8	.08
21.1	0.53	.03				0.25	1.93	7.72				49.3	8.4	.17
58.4	7.87	.13				5.46	0.90	.17				38.9	2.5	.06
25.9	0.84	.03				0.25	0.60	2.40				52.6	10.9	.21
40.6	7.87	.19				5.97	0.84	.14				104.	45.5	.44
22.4	0.99	.04				15.11	3.42	.23				31.5	17.3	.55
43.2	10.2	.24										51.8	8.9	.17
23.4	1.10	.05										51.8	7.6	.15
33.0	10.2	.31										110	29.5	.27
29.2	1.19	.04										68.5	21.6	.31
102.	11.2	.11										49.5	7.6	.15
43.2	1.22	.03										59.4	20.3	.34
107.	14.0	.13												
35.5	1.3	.04												
76.2	20.3	.27												
55.9	1.58	.03												
78.7	20.8	.26												
61.0	1.60	.03												
61.0	20.8	.34												
43.2	2.34	.05												
33.0	25.4	.77												
38.1	2.34	.06												
107.	43.2	.40												
24.1	2.79	.12												

Sources:

(1) (5) University of Manitoba
Dept. of Civil Engineering

(2) Dingman, (1973)

(3) (4) Anderson and Mackay (1973)


RAINFALL - RUN-OFF RELATIONSHIPS FOR
PERMAFROST & NON-PERMAFROST BASINS
X PERMAFROST BASIN
● PERMEABLE BASIN
O IMPERMEABLE BASIN
RUN-OFF (mm.)
RAINFALL (mm.)

River Channel Behaviour

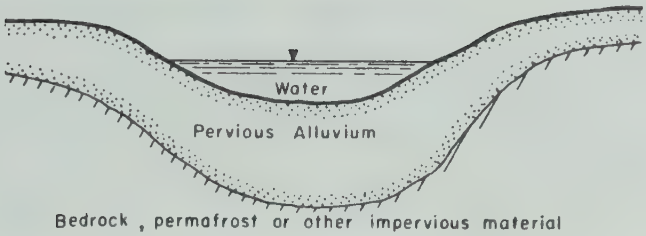
No direct effects of permafrost on the behaviour of major rivers were apparent from the limited data available. In all cases reported, the sensible heat of major river flows generally maintained a non-permafrost condition in the immediate sub-channel zone. The principal effect of the permafrost condition was the development of steep, undercut, and slumping channel banks on numerous streams flowing through but not over permanently frozen surficial deposits (Cooper and Hollingshead, 1973). No sediment data compiled specifically from permafrost areas were discovered.

Many peculiar characteristics of larger rivers in the permafrost regions could be attributed to the extreme sub-arctic and arctic climatic regimes rather than the occurrence of permafrost in the contributing basins.

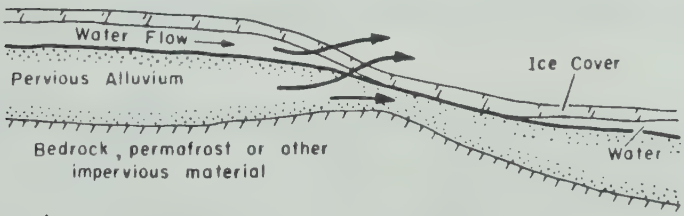
River channel forms peculiar to zones of ice accumulation with well developed side-terraces can be related to the annual ice regime of large northern rivers. Slush ice generation and accumulation such as that which occurs on the Nelson River and Churchill River in northern Manitoba can be analyzed by drawing an analogy between ice crystals within the flow and sediment, albeit that the crystals form spontaneously in the flow and are less dense rather than more dense than water. If this perspective is taken, it becomes apparent that in zones of low competency, the "ice-sediment" will rise and deposit on the surface of the river causing extreme ice accumulation phenomena in the upstream sections.

Unfortunately many of the relationships describing accumulated ice cover stability, the gross tractive force of the flow and border ice growth, and the energy budget for a moving slush ice surface are preliminary and cannot be generalized on the basis of the limited data available.

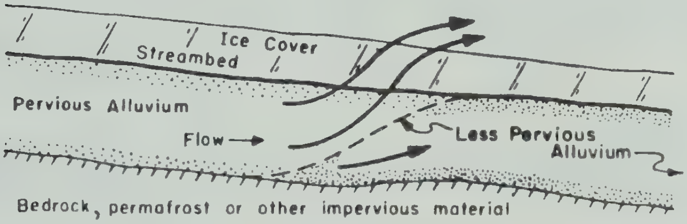
In smaller streams and braided channels, the occurrence of river icings, or near totally ice-filled river cross-sections, have been reported by Anderson and Mackay (1973,2) and Carey (1973). In permafrost regions, the possibility of shallow channels freezing entirely in mid-winter exists due to the climatic regime rather than the permafrost condition although low groundwater discharge during mid-winter would assist the occurrence. The channel



a. *The pervious alluvium is typically deeper beneath a river than away from the river.*



b. *An icing would occur in this case because the ice cover is frozen to the bed in a shallow reach where the cross section of the pervious sub-bed material is smaller.*



c. *Less-pervious sub-bed material might force sub-bed flow to break to the surface.*

Figure 3: River Cross-Sections and Profiles. The Solid arrows indicate possible paths of icing feed water (from Carey, 1973).

geometry and discharge conditions leading to extreme river icings were postulated by Carey as shown in Figure 3 but additional data are not available to quantify the conditions.

In spite of this lack of knowledge, major diversions of northern rivers are now under construction that will reduce flows in wide channels by over 90% of their normal mid-winter values.

Summary and Recommendations

From the above brief comments, it is apparent that both in the area of water supply to rivers and the area of in-channel water, energy, and sediment relationships, a great deal more fundamental data would be desirable. Excellent lists of research priorities for permafrost basins and northern rivers have been prepared by Williams and von Everdingen (1973) and Neill (1973) that merit direct examination.

In general, three major areas of future research needs are identified.

1) The need to develop and operate two or three specific permafrost basin studies to determine subsurface conditions, winter streamflow, and rainfall/runoff relationships,

2) the need to develop standard river basin form parameters and river channel behaviour surveys that include the compilation of now almost non-existent sediment data,

and 3) the need to exchange, compile, and report northern hydrologic data through some central Canadian office or agency.

If we could resolve that some single agency be designated as a repository and information center for permafrost hydrologic data, a first step would be made towards understanding the processes of water, energy and sediment in the major portion of Canada.

FEBRUARY, 1974

Post-Script

In an entirely different vein, I would like to propose that an issue of professional responsibility or lack of responsibility exists for hydrologists dealing with northern waters. Many of the replies to my limited survey of northern hydrologic knowledge were extremely useful, and I am grateful for them, particularly those given by researchers directly involved with northern environments. However, a significant number of replies from governmental agencies or large design offices assumed that the existence of permafrost had no significance to river behaviour or hydrology without data to support one view or the other.

However, many of the offices or agencies replying in this manner held extensive responsibilities for the development of diversions, hydro-electric projects and pipeline locations. Ethically, physicians to not permit experimental surgery with the human body, and by analogy it may well be that hydrologists should resist massive experiments with unknown northern water bodies until they are better understood.

In 1785, David Thompson (see Hopwood) wrote of a sacred monitou stone that had for centuries marked the main passage from Hudson Bay to the western interior of Canada. In 1786, the sacred marker was ordered removed from the passage because commercial interests felt that too much time was being wasted by the Indian employees of the fur traders in performing ceremonies of gratitude for the passage.

Thompson, and later Sir John Franklin, (1819) reported the demise of the "Painted Stone" but did not reflect upon the philosophy of its removal as they were merely employed as surveyors and explorers. Surely one hundred and eighty-eight years later, hydrologists might have evolved a philosophy that rises above the employee level and insists that time must be taken to understand the land before commercial exploitation proceeds.

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